Telecommunications Engineering, Analysis, and Modeling

The Telecommunications Engineering, Analysis, and Modeling Division conducts studies in these three areas for wireless and wireless-wireline hybrid applications.

Engineering includes assessment of the components of telecommunications systems; evaluation of protocol and transport mechanism effects on network survivability and performance; and assessment of the impact of access, interoperability, timing, and synchronization on system effectiveness in national security/emergency preparedness (NS/EP), military, and commercial environments.

Analysis is often performed in association with Telecommunications Analysis (TA) Services, which offers analysis tools online via the Internet. In addition, ITS can provide custom tools and analyses for larger projects or specialized applications.

Modeling is one of ITS' core strengths. Propagation models are incorporated with various terrain databases and data from other sources, such as the U.S. Census. Adaptations of historic models, and those for more specialized situations have been developed, enhanced, and compared. ITS engineers contribute their propagation modeling expertise to the ITU as well.

Our wireless test facilities and research capabilities allow ITS engineers to examine 2.5G and 3G technologies in detail. The Wireless Networks Research Center (WNRC) in combination with the 802.11 outdoor testbed can accommodate studies of emerging technologies and PCS, analysis of wireless protocols, and studies of wireless network effects, e.g., congestion, and capabilities, e.g., priority access. (See page 69 for information about the WNRC and page 63 for information about the wireless links at Green Mountain Mesa.)

Areas of Emphasis

ENGINEERING

PCS Applications

The Institute participated in the transition from Telecommunications Industry Association (TIA) committee TR46.2 to the Alliance for Telecommunications Industry Solutions (ATIS) subcommittee G3GRA (Radio Aspects of GSM/3G and Beyond). ITS is developing PCS interference models in a project funded by NTIA.

U.S. Coast Guard Rescue 21 Technical Consulting

The Institute assists the U.S. Coast Guard in testing and evaluating its new communication capabilities by acting as a third-party technical consultant. The project is funded by the U.S. Coast Guard.

ANALYSIS

Telecommunications Analysis Services

The Institute provides network-based access to research results, models, and databases supporting applications in wireless system design and evaluation. These services are available to government and non-government customers and are funded by fee-for-use and fee-for-development charges through an on-line CRADA.

Geographic Information System Applications

The Institute continues to develop a suite of Geographic Information System (GIS) based applications for propagation modeling and performance prediction studies. This work is funded by the DoD.

MODELING

Broadband Wireless Standards

The Institute develops new radio propagation algorithms and methods that improve spectrum usage of wireless systems. Technical standards are prepared that support U.S. interests in third generation (3G) broadband wireless systems. The project is funded by NTIA.

Propagation Model Development & Comparisons

The Institute compares and harmonizes existing propagation models, to improve their predictive accuracies and reduce the differences between their predictions. This project is funded by NTIA.

PCS Applications

Outputs

- Self-interference models for current and proposed PCS technologies.
- Technical contributions to an industry-developed inter-PCS interference standard for predicting, identifying, and alleviating interference related problems.

Personal Communications Services (PCS) has become an important resource for establishing emergency communication services following natural or man-made catastrophes. Such disasters can damage the wireline telecommunication system, forcing users to migrate to cellular resources. This sudden influx of traffic by private, commercial, civil, and Federal users results in wireless system overloads, a decrease in signal quality, and disruption of service in the affected area. Additional factors contribute to diminished channel capacity of a wireless network, such as co- and adjacent-channel interference and the operation of multiple, independent, non-interoperable systems servicing the same geographical area, often using the same frequency bands and infrastructure (base station sites and towers). National security/emergency preparedness (NS/EP) planners and network operators must understand these interference effects to operate effectively in an overloaded environment.

Increasing demand for wireless voice and data communications requires that the limited spectrum resources allotted to PCS be used as efficiently as possible. Code division multiple access (CDMA) is a major wireless technology used in second generation cellular systems and is becoming even more prominent in third generation systems. Code division schemes make efficient use of allotted spectrum and are relatively unaffected by noise. The capacity of technologies using CDMA is limited primarily by co-channel interference. Most automatic power control schemes in PCS systems increase power levels when the level of interference is unacceptable. This increases the interference level for all users of a common frequency band and can cause an exponential effect where all users of the spectrum are at maximum power levels and experiencing a diminished Quality of Service (QoS). With the increasing dependence on code division technology, a clear understanding of the effects of interference is essential to increase the efficiency of spectrum use.

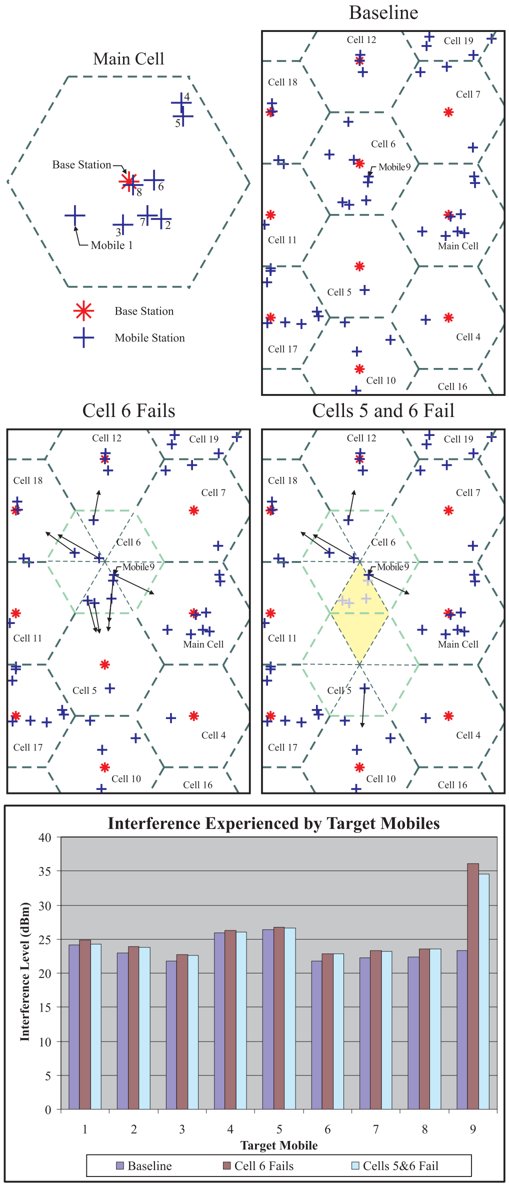
ITS has contributed to the understanding of inter-PCS interference by participating in the Telecommunication Industry Association (TIA) committee TR46.2 (Mobile & Personal Communications 1800-Network Interfaces). As a member of TR46.2, ITS contributed to the development of the Technical Service Bulletin "Licensed Band PCS Interference" (TSB-84A). This bulletin is a first step in characterizing the interfering environment caused by large numbers of active users and competing technologies. Since the completion of TR46.2's work, coverage of PCS interference concerns has been transferred to the Alliance for Telecommunications Industry Solutions (ATIS) subcommittee G3GRA (Radio Aspects of GSM/3G and Beyond), formerly T1P1.2. ITS continues to be involved in interference issues with this new group.

Detecting, identifying, and mitigating co-channel interference requires tools to characterize the interference experienced by PCS air-interface signals. PCS interference models are tools used to predict levels of interference and identify sources of interference. Several standard propagation models are accepted by industry members (i.e., Okumura and COST-231/Walfish/Ikegami) but no interference models have been developed or accepted. ITS is developing a series of PCS interference models starting with a model based on the ANSI/TIA/EIA-95-B standard, and leading to models covering proposed third generation (3G) systems. The model covers system-specific interference modeling to determine co-channel interference from both immediate and adjacent cells. It is based on the 95-B standard which produces a representation of an instantaneous 95-B air interface signal. The signal can contain outputs of multiple base stations with variable numbers of channels for each base station and can assign relative power levels for each individual channel. Both forward and reverse link processes are included in the model.

The input for the model is a sequence of binary values. This sequence can be random, but has no requirement to be random. For forward link signals, the appropriate Walsh code and orthogonal I and Q short pn codes spread the input sequence. For reverse link signals, the model modulates the input sequence with Walsh codes and then spreads the sequence with long and short pn codes. The resulting I and Q data streams pass through a baseband filter and a quadrature phase shift keyed (QPSK) or an offset QPSK (OQPSK) modulation scheme. The model calculates each channel signal contribution separately and then adds the processed signal to the other signal contributions to form a composite output signal. The power level for a single channel is an arbitrary gain factor of the baseband filter which is set separately for each channel. All the Walsh and pn code definitions come from requirements in the 95-B standard. The output of the model consists of a vector of numerical values representing a sampled QPSK or OQPSK signal. There is no error correction added to the input sequence, only spreading codes and modulation processes are used. This model does not check for recovery information contained in the input. Its only purpose is to determine how well the system can transmit the bits of the input binary sequence.

The output of the physical model is a sampled modulated signal which is the composite of the signals transmitted from all sources identified in a specified scenario. Software- and hardware-based simulations can use the sampled signal from the model to evaluate system designs. These simulations can characterize one-on-one, one-on-many, and many-on-one interference. As a result, potential solutions to congestion can be proposed to solve existing problems or to anticipate and avoid potential problems.

The figure displays a typical scenario showing the effects of system failure on the co-channel interference experienced by mobile stations in a cellular system. All cells in the system are populated by a single, centrally located base station, and a variable number of mobile stations which are randomly positioned within the cell. The main (center) cell contains eight mobiles, numbered as shown. Cell 6 contains eight mobiles, while cell 5 contains a single mobile. In the baseline state, all base stations are operating and are servicing their respective mobile stations. When the base station of cell 6 is removed, the mobiles of cell 6 are picked up by their nearest base station. In this situation, the main cell's base station picks up a single mobile (mobile 9), cell 5's base station picks up four mobiles, and the remainder are picked up by other surrounding cells. The plot shows the increase in co-channel interference experienced by the eight mobiles in the main cell, as well as mobile 9 whose service is transferred to the main cell. When the base station of cell 5 is removed, an assumption is made that the four mobiles that cell 5 picked up from cell 6 (those located in the yellow, diamond-shaped area) are no longer in position to receive service from any adjacent cell's base station. They are removed from service and no longer affect the interference levels of nearby mobiles. Cell 5's single mobile is picked up by its adjacent cell, and the interference levels for the nine mobiles being observed are recalculated. The plot shows the resultant change in interference. In most cases, interference is reduced due to the loss of the four mobiles that lost service. Mobiles 6 and 8 show almost no change in experienced interference due to their proximity to the main cell's base station.



Typical system load analysis scenario utilizing ITS' PCS co-channel interference model.

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U.S. Coast Guard Rescue 21 Technical Consulting

Outputs

- Written technical feedback on design and test documents.
- Radio Frequency (RF) analysis.
- Witnessing of field and factory tests on location.
- Meeting attendance as subject matter experts.

Rescue 21 is a project undertaken by the U.S. Coast Guard to modernize and upgrade its current communications capability. This system should enhance the Coast Guard's capabilities by increasing its response coverage area, by providing a common operation environment, and by providing Coast Guard personnel with modernized tools to perform their missions. Rescue 21 is the maritime emergency response (911) system for the coastal U.S. and the communications infrastructure for all Coast Guard coastal missions. Rescue 21 will consist of many operating regions along the U.S. coast and waterways. Each region will have a Group Communications Center (GCC) that is networked to a Search and Rescue Station and several Remote Transceiver Sites. Rescue 21 is a hybrid communications system composed of wireless and wired components.

ITS has an Interagency Agreement with the Coast Guard to provide technical expertise during the Developmental Testing and Evaluation (DT&E) phase of Rescue 21. DT&E includes two levels of testing — a Formal Qualification Test (FQT) at the contractor's facility, and a System Integration Test (SIT) in the field. ITS provided technical consulting to the Coast Guard for the entire DT&E phase. For both FQT and SIT, written analysis and recommendations were provided on the test approach, test plans, and test procedures. ITS also participated in the witnessing of both tests on site.

ITS's technical contributions were focused mainly in the following areas:

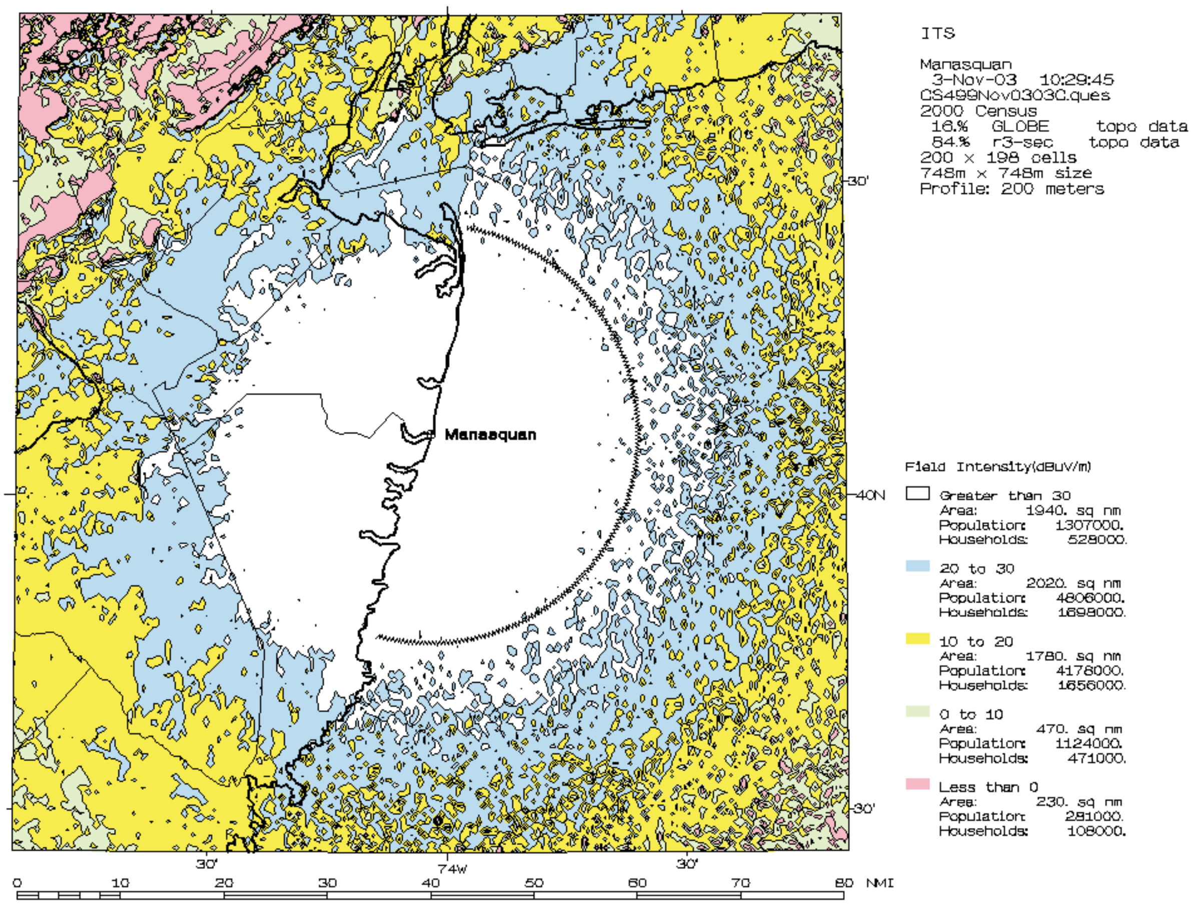
Performance Availability
All GCC's in the system are networked together with the rest of the Coast Guard communications functions, and must have the capacity to track Coast Guard assets and emergency calls as they are passed from region to region. ITS provided analysis of the effect of network traffic on system availability.

RF Coverage
The Rescue 21 system is required to provide RF coverage along the entire U.S. coastline, lakes, and intercoastal waterways, out to a 20 nautical mile boundary. ITS reviewed the SIT test plans to ensure that the test procedures would result in a reasonable proof of the coverage requirement. Measurement methods and sampling paths and locations were analyzed for compliance with TSB-88 and standard practice for communication coverage testing.

Propagation Modeling
In support of the RF coverage analysis, ITS provided the Coast Guard with antenna coverage predictions using the Irregular Terrain Model (ITM) and the Advanced Propagation Model (APM). These models were used to anticipate the effects of ocean wave heights on the coverage area (see the figure on the next page).

Voice Quality
ITS is a recognized expert in the area of Voice Quality analysis, and provided written recommendations to the Coast Guard for analyzing the voice quality received over Rescue 21 wireless channels against the specifications in the system requirements.

Direction Finding
The new system will be able to create a line of bearing in the direction of vessels in distress within one degree of accuracy. ITS used its experience with direction finding systems in the analysis of test plans and procedures.



Effect of 10m waves on propagation coverage area (area shown is the New Jersey shoreline).

P25 Specifications and Requirements
The Rescue 21 Performance Specification requires interoperability with other emergency response agencies through utilization of P25 equipment. ITS applied its expertise in this area to the review of test documents for parts of the system which use P25.

RF Interference
One key factor in RF coverage is the consideration of the RF noise environment. ITS analyzed test plans and procedures to ensure proper measurement of the RF environment and the expected effects on RF coverage. In addition, one of the upgrades Rescue 21 provides to the Coast Guard over its current communications system is the capability for simultaneously communicating over multiple channels. ITS provided technical input in the area of intermodulation interference during simultaneous communications.

As Rescue 21 nears the end of DT&E, ITS continues to provide technical feedback and analysis on the test data and results, helping the Coast Guard verify whether or not the system specifications and technical requirements have been met.

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Telecommunications Analysis Services

Outputs

- Internet access for U.S. industry and Government agencies to the latest ITS engineering models and databases.
- Contributions to the design and evaluation of broadcast, mobile, radar systems, personal communications services (PCS) and local multipoint distribution systems (LMDS).
- Standardized models and methods of system analysis for comparing competing designs for proposed telecommunication services.

Telecommunications Analysis Services (TA Services) gives industry and Government agencies access to the latest ITS research and engineering on a cost reimbursable basis. It uses a series of computer programs designed for users with minimal computer expertise or in-depth knowledge of radio propagation. The services are updated as new data and methodologies are developed by the Institute's engineering and research programs.

Currently available are: on-line terrain data with 1-arc-second (30 m) for CONUS and 3-arc-second (90 m) resolution for much of the world, and GLOBE (Global Land One-km Base Elevation) data for the entire world; the U.S. Census data for 2000, 1997 update, and 1990; Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases (ARCINFO). For more information on available programs, see the Tools and Facilities section (pp. 68–69) or call the contact listed below.

TA Services is currently assisting broadcast television providers with their transition to digital television (DTV) by providing a model for use in advanced television analysis (high-definition television, advanced television, and digital television). This model allows the user to create scenarios of desired and undesired station mixes. The model maintains a catalog of television stations and advanced television stations, updated weekly from the FCC, from which these scenarios are made. Results of analyses show those areas of new interference and the population and number of

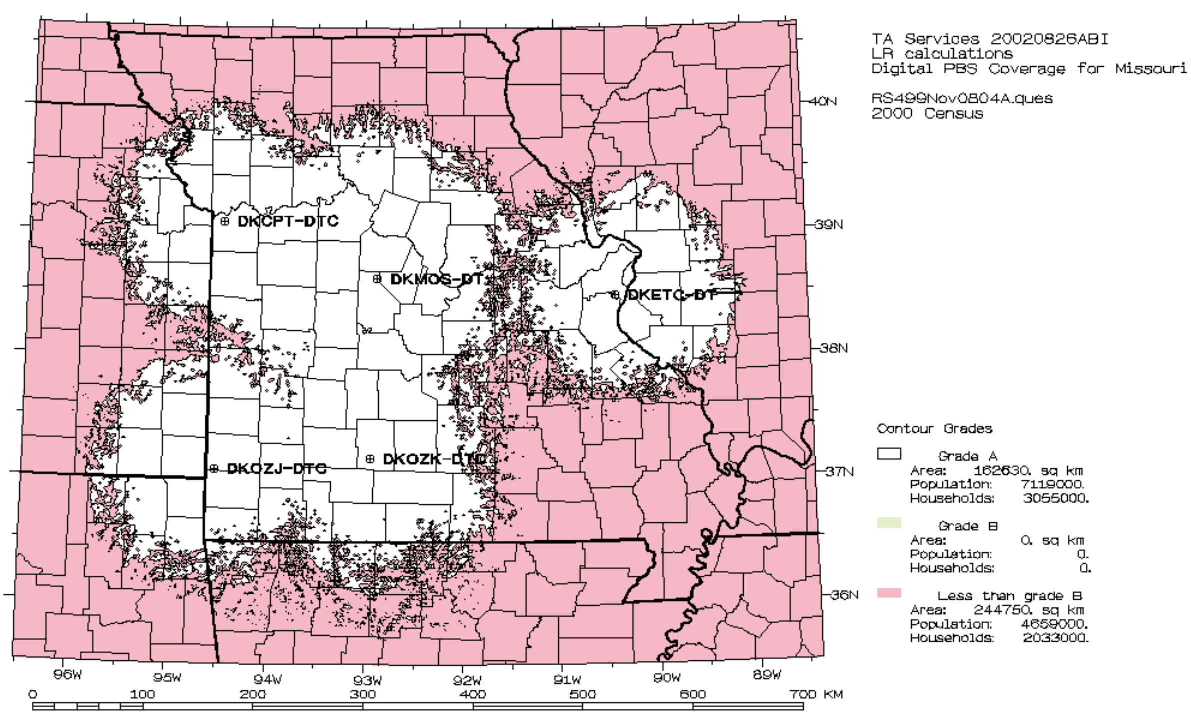

Figure 1. Digital PBS TV coverage for Missouri.

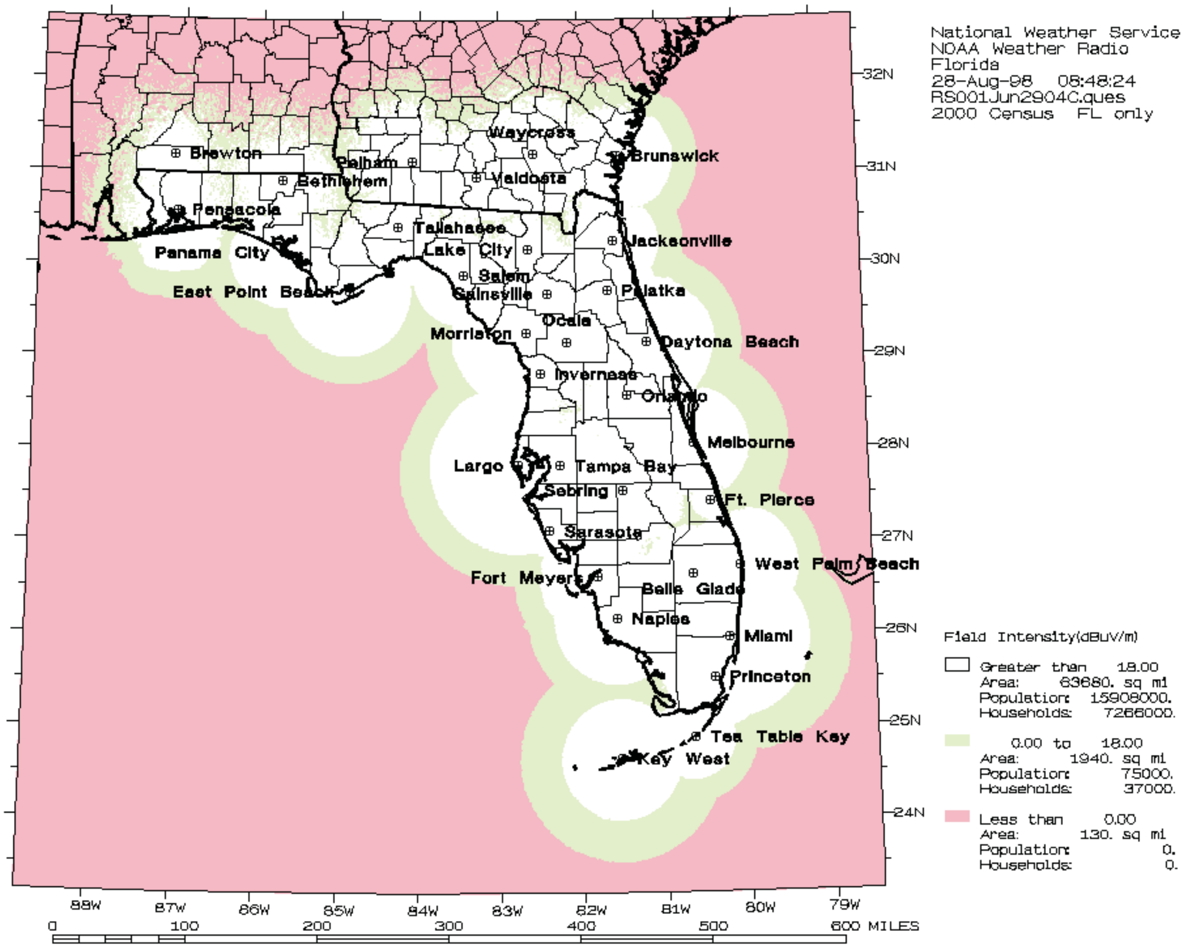

Figure 2. NWS station coverage for Florida.

households within those areas. The model can also determine the amount of interference a selected station gives to other stations. This allows the engineer to make modifications to the station and then determine the effect those modifications have on the interference that station gives other surrounding stations. In addition to creating graphical plots, the program creates tabular output which shows the distance and bearing from the selected station to each potential interferer as well as a breakdown of the amount of interference each station generates. This year, using this same program, all of the Public Broadcasting Service's (PBS) digital TV stations (350) were converted to ArcView shape files and sent to PBS for use with their own GIS software. Figure 1 on the previous page shows the digital PBS TV coverage for Missouri.

TA Services is also assisting the National Weather Service (NWS) in locating additional sites to increase its coverage for weather radio reports and emergency warning broadcasts, such as those issued in September 2004 for hurricanes on the east coast. Figure 2 above shows the calculated NWS coverage for Florida. TA Services calculates that 99.5% of the Florida population should be able to hear NWS weather radio broadcasts.

All models in TA Services and their outputs can be accessed via a network browser at http://flattop.its.bldrdoc.gov.

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Geographic Information System Applications

Figure 1. An analysis area created for the city of Boston.

Outputs

- Propagation coverages for one or more transmitters draped over surfaces.
- Interference and overlap coverages.
- 2D and 3D visualization environments.
- Fly-through visualization capabilities.

ITS has developed and continues to improve a suite of Geographic Information System (GIS) based applications incorporating propagation models for outdoor and indoor analyses. Databases for GIS use, including terrain, satellite and aircraft imagery, roads and other transportation infrastructure layers, building data and population, are becoming more available and affordable. These databases can be easily connected to GIS systems and can be shared among users in web-based or standalone GIS applications. The Institute has developed generic and application-specific GIS programs that aid Government agencies, private cellular companies, public and private television stations, transportation companies and consultants in the performance of their missions to efficiently manage the telecommunications infrastructure of the United States.

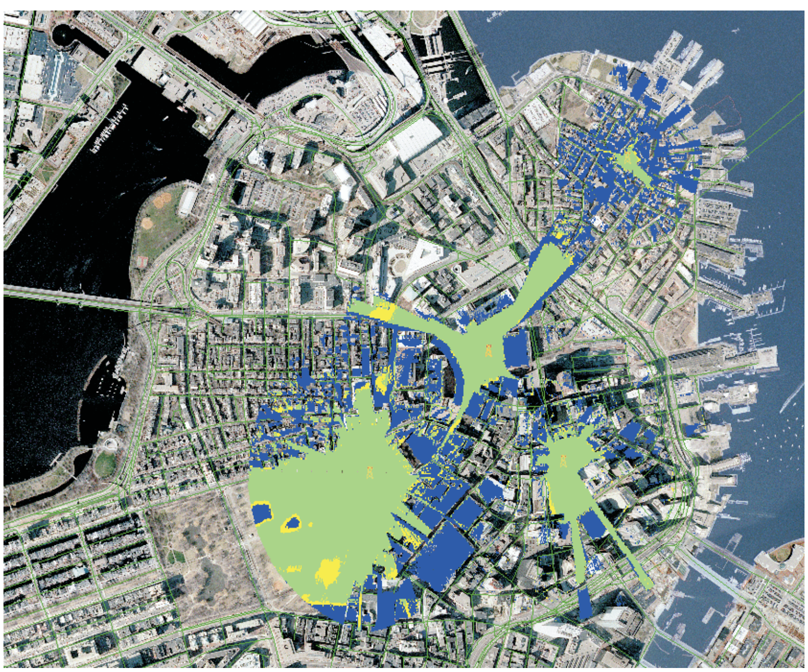

Figure 2. A composite coverage of four transmitters.

One GIS based tool developed by ITS is the Communication Systems Planning Tool (CSPT). CSPT is a menu and icon driven propagation model developed for frequencies from 20 MHz to 20 GHz that allows the user to connect to a variety of image catalogs and terrain libraries that cover most of the world. The user can create specific analysis areas using these catalogs and libraries and can then perform propagation scenarios for his/her application. These applications can range from outdoor coverage studies of large-scale areas of hundreds of square miles to indoor propagation studies of one building in an urban environment.

Figure 3. Signal to interference analysis with red indicating significant interference.

Current work efforts involve the development of standalone and web-based GIS tools for outdoor and indoor propagation modeling as well as visualization capabilities that allow the user to fly into the analysis area and move around the environment as the tool updates the visualization imagery to the resolution appropriate to the display environment. The user can then drape coverages of outdoor and/or indoor scenarios and move around the environment to examine the output.

The general flow of the CSPT GIS Tool is as follows. The user defines an area within which a study will be performed. This analysis area can be defined graphically by zooming into a map of the world or of the U.S. or by defining the latitude and longitude of the boundaries of the desired area. The user then imports desired GIS information such as political boundaries, roads, rivers, special imagery, or application-specific GIS data. Figure 1 shows an analysis area created for the city of Boston.

After creating the analysis area, the user creates or imports transmitter, receiver, and antenna data. Lastly, the user selects the type of coverage and the propagation model to be used in the analysis. Figure 2 shows a composite analysis of the coverage of four transmitters located throughout the city. The analysis can be limited to sectors and specified distances around each transmitter to speed up calculations and focus on an area of interest.

Interference analyses can be run allowing the user to specify the signal to interference contours and colors as shown in Figure 3.

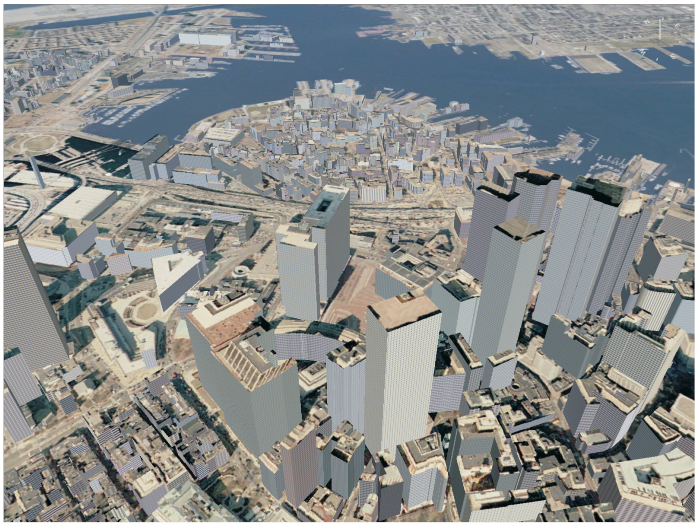

Figure 4. A 3D visualization of the city of Boston.

Coverages, composites and interference analyses can be imported into visualization tools allowing the user to see and often fly through their studies so that a better understanding of the analysis results can be obtained. Figure 4 shows a 3D visualization of the Boston skyline made by such a visualization tool. Many such tools exist and ITS is developing methods to export CSPT coverages into such visualization tools.

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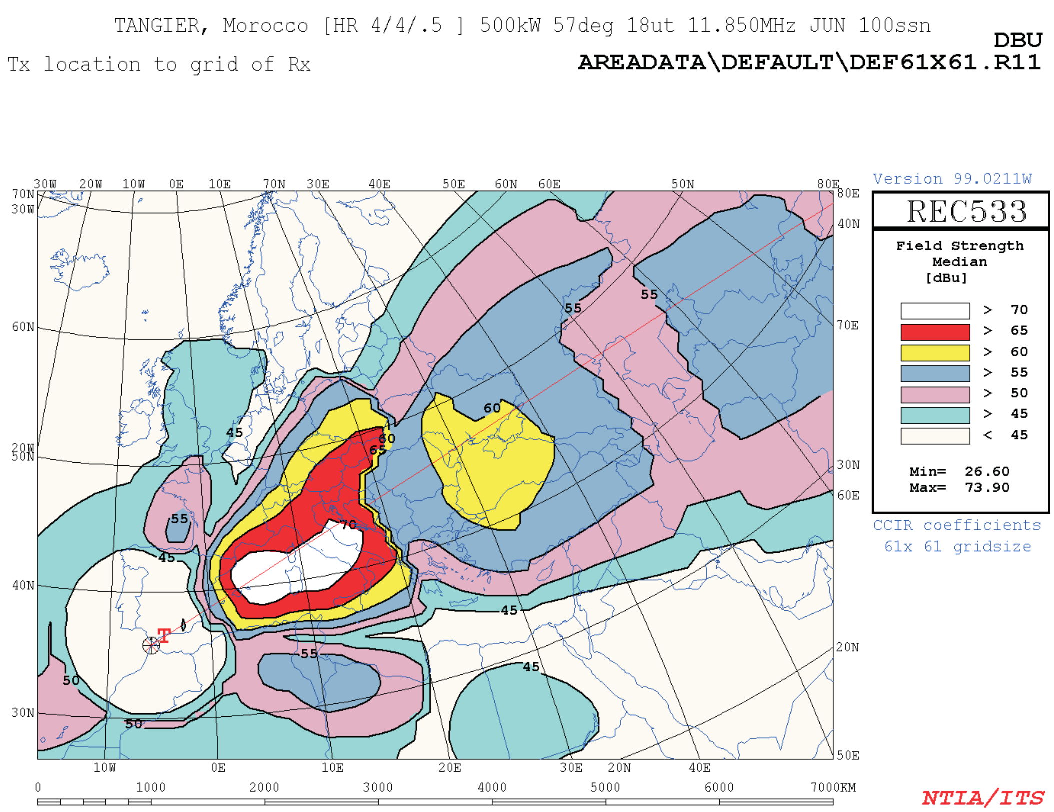
Broadband Wireless Standards

Outputs

- Preparation of technical standards and documents for the ITU-R that support the U.S. interest in broadband wireless systems.
- Development of new radio propagation algorithms or methods that improve spectrum usage of wireless systems.

Wireless communication has seen tremendous growth in recent years, in both the number of users and the types of new services, beyond simply voice communications. In particular, there has been an emphasis on Internet and broadband data uses. These additional users and new services require greater bandwidths than before, which for wireless users means more radio spectrum. As growing numbers of users require ever more spectrum, it is necessary to be able to predict signal coverage for various wireless services more accurately, so that everyone can share the available spectrum and peacefully coexist without interference. The development of radio-wave propagation prediction models for accurate prediction of signal coverage supports broadband wireless standards for these broadband wireless systems.

Historically, radio propagation model development tended to be very service specific, with models for the broadcast FM radio and television service or for the land mobile radio service and little or no overlap in applicability between the models for different services. This service specific approach was adequate for a regulatory philosophy that assigned different, exclusive blocks of the radio spectrum to different services in a proprietary fashion. However, this lack of overlap between models can also create an impediment to the shared use of spectrum by different services or wireless applications, because, for example, a model that is used to predict intra-service system availability and interference might not also apply flexibly and accurately to inter-service interference predictions. To overcome this problem, ITS



Output from the High Frequency propagation software for international frequency coordination, developed by the ITU and maintained by ITS.

and other research organizations have been developing and evaluating propagation models to predict wireless signal coverage more accurately and flexibly, both within and across services.

The ITS Irregular Terrain Model (ITM) is one such general purpose model for the prediction of radio propagation over tropospheric circuits, in the frequency range 20 MHz – 20 GHz. This model may be used for radio propagation predictions in its area (i.e., site-general) mode, when little, if any, detailed information is available for the path. It may also be used for radio propagation predictions in its point-to-point (i.e., site-specific) mode, when detailed terrain elevation data are available for the path. For either mode, the model first generates the predicted reference attenuation (i.e., the computed median attenuation in excess of free space) as a function of distance, based on three ranges, corresponding to the dominant radio propagation mechanisms in these ranges: line-of-sight, diffraction and tropospheric scatter. This computed reference attenuation is then modified by the desired quantiles of the time, location and situation variabilities, combined as necessary to give reliability and confidence estimates.

ITS participates in the international development of radio propagation prediction models that can be used by spectrum managers and system planners of land mobile, terrestrial broadcast, maritime mobile and certain applicable fixed (e.g., point-to-multipoint) services, among others. ITS supports this effort by participation in the International Telecommunication Union — Radiocommunication Sector (ITU-R) Study Group 3 (Radiowave Propagation). Study Group 3 recently developed and adopted a radio propagation model which blends features that the different services had previously used independently, thereby clarifying and unifying planning and coordination activities across these services. This recommendation, Recommendation ITU-R P.1546, is usually considered to be a site-general model, although, for improved accuracy, it specifies numerous adjustments and corrections to the basic method that are very nearly site-specific in their application. In preparation for the recently-held first session of the Regional Radio Conference (RRC-04) and to support the work of the Intersessional Planning Group (IPG) established by the RRC-04,[1] Study Group 3, Working Party 3K (WP 3K, point-to-area propagation) and, in particular, Subgroup 3K-2 have undertaken a number of significant revisions of Recommendation ITU-R P.1546. For several years, an ITS engineer has served as chairman of Subgroup 3K-2.

As a much needed adjunct to this work, Subgroup 3K-1 of WP 3K and Study Group 3 is examining and evaluating proposals for the use of several different site-specific radio propagation models that are broadly applicable and flexible for intra- and inter-service planning and coordination uses, when detailed terrain elevation data are available. ITS, in cooperation with U.S. Study Group 3, has submitted two U.S. contributions to WP 3K proposing the ITM (point-to-point mode) and a closely related hybrid radio propagation model, based on Recommendations ITU-R P.1546 and P.452. The performance of these models will be thoroughly evaluated in the upcoming year with the results of these studies provided to WP 3K through further U.S. contributions.

In addition to the above areas, WP 3K deals with propagation aspects of short-path personal communications and wireless local area networks (WLAN) in the frequency range 300 MHz to 100 GHz, and wireless access systems in these frequency ranges. Time permitting, recently obtained propagation data for dense and moderate urban and suburban environments will be submitted as additional U.S. contributions to WP 3K.

ITS also participates in the work of Working Parties 3J (propagation fundamentals), 3M (point-to-point propagation, earth-space propagation, interference and coordination) and 3L (ionospheric propagation). ITS continues to be responsible for the HF (3–30 MHz) propagation software developed by the ITU for international frequency coordination. The ITU website, http://www.itu.int/ITU-R/software/study-groups/rsg3/databanks/ionosph/index.html, links to an ITS web site with the following reference, HF sky-wave propagation (Rec. P.533) (available from the ITS web site) http://elbert.its.bldrdoc.gov/hf.html. An example of the type of output that the software can produce is shown in the figure on the previous page.

[1] The RRC-04 is the first of two scheduled sessions of the international conference to establish agreements and standards for the coordination and planning of digital terrestrial broadcast services (radio and television) in parts of the ITU-R's Regions 1 and 3 of the world.

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Propagation Model Development & Comparisons

Outputs

- Improvement of the effective height algorithm in the ITS Irregular Terrain Model (ITM).

Propagation model development in FY 2004 focused on improving the effective height algorithm in the ITS Irregular Terrain Model (ITM). Radio propagation predictions made using the ITM are highly influenced by the effective heights of the terminals. The effective heights are used to compute several intermediate quantities that may have a large impact on the prediction.

To estimate effective heights in the point-to-point (site-specific) mode, the ITM utilizes least squares fitting to a portion of the terrain profile, and a comprehensive path profile analysis. The portion of the profile utilized depends on whether or not the direct ray's elevation has terrain clearance. If the path is line-of-sight (LOS), the least squares fit is applied to the central 80% of the terrain elevations between the terminals, yielding a single linear function with distance, extrapolated to each terminal's endpoint to estimate its effective height. If the path is transhorizon, a least squares fit is applied to the central 80% of the terrain elevations between each terminal and its corresponding radio horizon distance. For both paths, each of the terminals' effective heights is always limited to be at least the corresponding height above ground of the radiation center.

For any given transhorizon path, polarization, and frequency of operation, the net effect of increasing the effective heights is to reduce ITM's predicted reference attenuation. The converse is also valid, but reductions in the effective heights are limited to the corresponding terminals' heights above ground. However, for any given LOS path, polarization, and frequency of operation, the possibility of constructive and destructive "interference" effects between the direct ray and the ray reflected from the ground may or may not reduce ITM's predicted reference attenuation as the terminals' effective heights increase, up to a point. Beyond that point, increasing the terminals' effective heights will lead to reductions in ITM's predicted reference attenuation.

Previous comparison studies of measured propagation data and ITM's point-to-point mode predictions have indicated that, in some cases, the algorithm tends to overestimate the terminals' effective heights. This is true of the datasets with low terminal radiation center heights above ground. However, examination of individual measurement data and predictions indicated that, for many of these, an effective height estimate greater than the radiation center height above ground improved ITM's prediction accuracy, compared to substitution of the radiation center height above ground for the effective height. Figures 1 and 2 show examples of how different the predictions can be for the two cases. In some, the effective height that improved the prediction accuracy exceeded the existing algorithm's estimate. Also found were instances where improved prediction accuracy would result if the terminals' effective heights were less than the radiation center heights above ground.

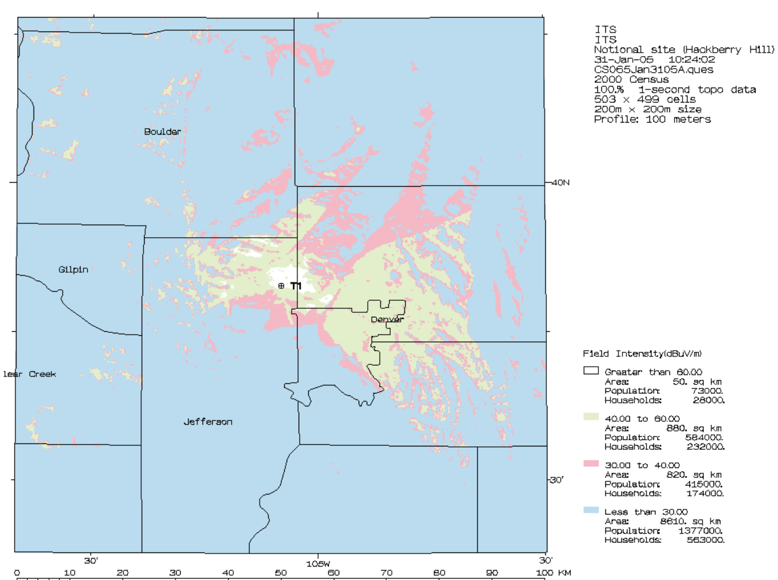

Figure 1. CSPM plot showing predicted radio coverage using ITM with the existing effective height algorithm.

The preceding discussion suggests that the effective height algorithm in ITM can be improved. However, key aspects should be retained, e.g., the subdivision of paths into LOS and transhorizon classifications, and the rule that any adjustments or limitations to the effective heights apply equally to both terminals. The latter condition is necessary to preserve reciprocity. Unfortunately, it limits the range of improvement in the prediction accuracy, because if one terminal is high while the other is low, the effective height of the low terminal is more influential on the prediction accuracy.

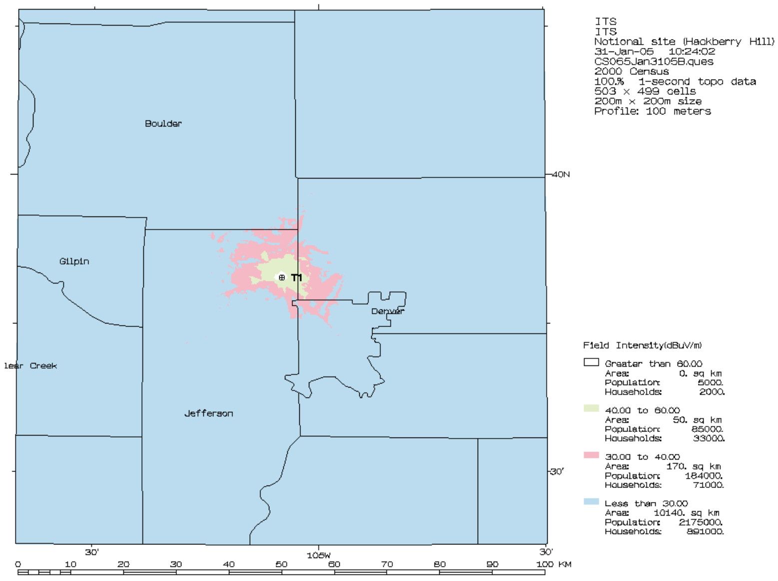

Figure 2. CSPM plot showing predicted radio coverage using ITM with effective heights set to the structural height above ground.

Two approaches to defining the terminals' effective heights have been studied thus far. Both are motivated by determining an effective ground reflection point and least squares fitting portions of the terrain profile centered on this point. The first approach was to search the terrain profile, or portion thereof, depending upon whether or not the path was LOS or transhorizon, for the point or points of reflection, based on the assumption that the terrain elevation followed a straight line with distance between any two adjacent profile points. A further condition was applied to each point detected: it must be intervisible to both terminals. We therefore label this the "glint" approach. Depending on whether no glint, one glint, or more than one glint was detected, varying portions of the terrain profile, centered on the glint or glints, were then least squares fitted and the resulting line or lines were extrapolated to the terminals' locations to estimate the effective heights. If no glint was detected, the method defaulted to the existing effective height algorithm. Unfortunately, many of the paths had no detected glint, so this approach demonstrated no or only very limited improvement.

A second approach was therefore devised that searched the terrain profile, or portions thereof, depending upon whether or not the path was LOS or transhorizon, for the point of minimum clearance for the first Fresnel zone. For LOS paths, the first Fresnel zone was referenced to the direct ray between the terminals' heights above ground. For transhorizon paths, the first Fresnel zone was referenced to the ray between the terminal's height above ground and the terrain obstacle comprising its corresponding radio horizon. We thus label this the "minimum clearance" approach. Varying sections of the terrain profile were then least squares fitted and the resulting straight line or lines extrapolated to the terminals' locations to estimate the corresponding effective heights. The results of this approach usually improved the mean prediction accuracies. Although this approach is more robust, it is also suboptimal, because the prediction accuracies' standard deviations were often increased when compared to the existing effective height algorithm. Furthermore, when compared to either the means or the standard deviations of the prediction accuracies for the effective heights set at the terminals' heights above ground, there was no improvement in the prediction accuracies' statistics.

Additional effort to improve on the existing effective height algorithm is plainly required. Limiting the terminals' effective heights may help to reduce the minimum clearance approach's prediction accuracies' (absolute values of the) means and standard deviations. However, these limits must be reciprocal for the algorithm to have wider utility and applicability.

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